AN EXPERIMENTAL STUDY OF THE AUDITORY POWERS OF THE GIANT SILKWORM MOTHS (SATURNIIDÆ)

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This is a companion paper to the "Auditory Powers of the Catocala Moths" by C. H. Turner and Ernst Schwarz. The latter paper embodies the results of a field study and this epitomizes a laboratory investigation. The habits of resting quietly upon a tree trunk and of flying, when disturbed, to a nearby tree renders the Catocalæ excellent material for field study; the fasting habits of the Saturniidæ render them equally good material for laboratory work. The paper on the Catocala moths contains both a historical resume and a bibliography; hence they are not needed in this contribution.

In these experiments the following moths were used: 79 specimens of *Samia cecropia* Linn., 104 of *Philosamia cynthia* Drury, 41 of *Callosamia promethea* Drury and 81 of *Telea polyphemus* Cramer. These insects were confined beneath wire dish covers. Each moth was numbered and one insect, in case of mated individuals one pair, was placed beneath a cover.

These experiments were conducted in an out-of-doors insectary the north wall of which is constructed almost entirely out of wire netting. The other three wooden walls are window-less and lined with shelves. These walls and the shelf-rests are supported by the ground. The wooden floor rests on the ground, but is not attached either to the walls or the shelf-rests; indeed, a space of from one to three feet separates the floor from the walls. Suspended from the ceiling by picture wire, there is a heavy swinging shelf. The subjects of these experiments were kept on these shelves. Since I always stood on the floor when sounding any of the instruments, it was impossible for the vibrations to reach the moths by any medium other than the air.

These experiments were conducted in the mornings between five and half past seven and in the afternoons between three and seven. On Saturdays and Sundays experiments were sometimes conducted all day long.

For producing stimuli the following instruments were used: an adjustible organ pipe, with a range for all notes of two octaves and for one note of three; an adjustable pitch pipe, and an Edelmann's Galton whistle. Such moths as responded did so by moving the wings as though about to fly. In the early experiments, before I had many moths on hand, each moth was tested with all of these instruments; because I hoped to determine the upper and lower threshold of hearing for each specimen. Later on, partly because I became convinced that there are theoretical

TABLE I.

Number: 3–VI–14: 1. *Specimen: Callosamia promethea*, female.

Place: Confined, under a wire dish cover, on the swinging shelf.

Method: At each trial the instrument was sounded five times at intervals of a minute and records made of the moth's behavior.

Trials.	Date.	Time.	Stimulus.	Vibrations Per Second.	Temperature.	Tests.					Remarks.
						1	2	3	4	5	
1	3–VI	6:30	P.P.	680	71	*	*	*	*	*	Response vigorous.
2	4–VI	6:00	P.P.	680	78	*	*	*	*	*	Response vigorous.
3	4–VI	6:10	G.W.	3,480	78	—	—	—	—	—	
4	4–VI	6:15	O.P.	512	78	*	*	*	*	*	Response vigorous.
5	4–VI	6:20	O.P.	256	78	*	*	*	*	*	Response slight.
6	4–VI	6:25	O.P.	128	78	*	*	*	*	*	
7	4–VI	6:30	O.P.	64	78	*	*	*	*	*	
8	6–VI	10:05	P.P.	680	86	—	—	—	—	—	Whistle held in rear.
9	6–VI	10:10	O.P.	512	86	—	—	—	—	—	Whistle held in rear.
10	6–VI	10:15	O.P.	256	86	—	—	—	—	—	Whistle held in rear.
11	6–VI	10:20	O.P.	128	86	—	—	—	—	—	Whistle held in rear.
12	6–VI	10:25	O.P.	64	86	—	—	—	—	—	Whistle held in rear.
13	6–VI	10:30	P.P.	680	86	*	—	—	—	—	Whistle held in front.
14	6–VI	10:35	O.P.	256	86	*	*	*	*	*	Whistle held in front.
15	6–VI	15:00	P.P.	680	96	*	*	*	—	—	Whistle held in front.
16	6–VI	15:10	O.P.	256	96	—	*	—	*	*	Whistle held in rear.
17	6–VI	15:20	O.P.	64	96	—	—	—	—	—	
18	6–VI	15:30	O.P.	256	96	*	*	*	*	*	

Explanation of abbreviations; G.W. means Galton whistle; O.P., organ pipe; P.P., pitch pipe; in the second column, the roman numerals stand for months and the Arabic for days; in the third column, the hours are numbered from 1 to 24, beginning at 1 A.M.

reasons why the thresholds cannot be accurately determined by this method and partly on account of practical difficulties, I confined my experiments to a few notes of the middle range. When I remind you that I often had on hand from fifty to seventy-five moths, you will readily see that it was impossible to test each moth, each time, with the entire range of pitches.

The results of these investigations were recorded upon blanks that were prepared especially for this work. A portion of one of those blanks is reproduced in the preceding table.

After the work on all of the moths had been completed, the contents of these blanks were condensed into the following tables.

TABLE II.

REACTIONS OF GIANT SILK-WORM MOTHS TO SOUNDS.

Name of the Specimen.	Number of Individ.	Number of Trials.	Per Cent. of Responses.										
			0	1 to 9.	10 to 19.	20 to 29.	30 to 39.	40 to 49.	50 to 59.	60 to 69.	70 to 79.	80 to 89.	90 to 100.
Samia cecropia													
Males	38	380	1	0	0	0	1	0	1	2	0	0	33
Females	41	615	0	0	0	1	0	1	5	0	1	1	32
Total	79	995	1	0	0	1	1	1	6	2	1	1	65
Philosamia cynthia													
Males	50	950	19	0	0	2	4	4	9	3	1	1	7
Females	54	875	10	0	1	3	0	1	11	4	4	1	19
Total	104	1,825	29	0	1	5	4	5	20	7	5	2	26
Callosamia promethea													
Males	23	380	4	0	0	0	3	0	5	0	0	1	10
Females	18	495	1	0	0	0	1	0	1	2	5	2	6
Total	41	875	5	0	0	0	4	0	6	2	5	3	16
Telea polyphemus[1]													
Males	39	950	36	0	0	1	0	0	0	0	0	0	2
Females	39	950	39	0	0	0	0	0	0	0	0	0	0
Total	78	1,900	75	0	0	1	0	0	0	0	0	0	2

[1] The above table does not record the three specimens of *T. polyphemus*, which were used in the special tests recorded on pages 333–334.

TABLE III.

RESPONSES OF *Samia cecropia* TO SOUND.

Instrument.	Pitch Vibra. per Second.	Individuals Participating.			Number of Trials.			Per Cent. of Response.		
		Males.	Females.	Total.	Males.	Females.	Total.	Males.	Females.	Total.
O.P.	64	1	4	5	5	35	40	100	100	100
O.P.	128	2	1	3	10	5	15	50	100	67
O.P.	256	6	13	19	25	75	100	100	100	100
O.P.	512	1	2	3	5	15	20	100	100	100
P.P.	680	26	34	60	310	360	670	94	89	91
P.P.	870	2	2	4	15	10	25	33	0	20
G.W.	3,480	11	19	30	60	100	160	100	70	81
G.W.	4,645	0	1	1	0	5	5		100	100
G.W.	6,200	1	0	1	10	0	10	50		50
G.W.	6,960	0	1	1	0	5	5		100	100
G.W.	9,290	1	0	1	5	0	5	100		100

Explanation of abbreviations used in above table: O.P., organ pipe; P.P., pitch pipe; G.W., Galton whistle (Edlemann's).

TABLE IV.

EFFECT OF AGE ON THE RESPONSES OF *S. cecropia* TO SOUND.

Age in Days.	Individuals Participating.			Number of Trials.			Per Cent. of Responses.		
	Males.	Females.	Total.	Males.	Females.	Total.	Males.	Females.	Total.
0–1	26	23	49	205	200	405	80	80	80
1–2	7	10	17	60	55	115	100	82	91
2–3	5	11	16	30	65	95	100	54	72
3–4	2	12	17	10	120	130	100	100	100
4–5	4	4	8	20	25	45	100	100	100
5–6	2	3	5	10	20	30	100	75	83
6–7	4	3	7	25	30	55	100	83	91
7–8	1	2	3	15	20	35	100	100	100
8–9	1	2	3	10	15	25	100	100	100
9–10	2	4	6	25	30	55	100	100	100
10–11	0	3	3	0	15	15		100	100

TABLE V.

EFFECT OF TEMPERATURE ON THE RESPONSES OF *S. cecropia* TO SOUNDS.

Temperature in F. Degrees.	Individuals Participating.			Number of Trials.			Per Cent. of Responses.		
	Males.	Females.	Total.	Males.	Females.	Total.	Males.	Females.	Total.
50–59	11	6	17	130	70	200	83	53	70
60–69	9	14	23	130	110	240	74	87	80
70–79	4	16	20	40	170	210	100	94	95
80–89	18	27	45	155	235	290	97	96	96
90–99	0	4	4	0	35	35		100	100

TABLE VI.

EFFECT OF MATING ON THE RESPONSES OF *S. cecropia* TO SOUND.

	Number of Individuals.	Number of Trials.	Per Cent. of Responses.
Males:			
Unmated.....	31	320	88
Mated	7	120	97
Total.....	38	440	90
Females:			
Unmated.....	36	520	86
Mated.....	5	55	73
Total.....	41	575	85
Grand total.....	79	1,015	88

TABLE VII.

RESPONSES OF *Philosamia cynthia* TO SOUND.

Temperature in F. Degrees.	Individuals Participating.			Number of Trials.			Per Cent. of Responses.		
	Males.	Females.	Total.	Males.	Females.	Total.	Males.	Females.	Total.
60– 69	25	23	48	145	120	265	31	42	33
70– 79	43	43	86	410	420	830	36	60	48
80– 89	23	34	57	245	300	545	33	67	51
90– 99	6	11	17	130	65	195	58	77	67
100–109	0	8	8	0	40	40		88	88

TABLE VIII.

EFFECTS OF MATING ON THE RESPONSES OF *Philosamia cynthia* TO SOUND.

	Number of Individuals.	Number of Trials.	Per Cent. of Responses.
Males:			
Unmated.....	47	880	38
Mated.....	8	65	31
Total.....	55	945	36
Females:			
Unmated.....	50	835	63
Mated.....	8	90	56
Total.....	58	925	61

TABLE IX.

EFFECT OF AGE ON THE RESPONSES OF *Philosamia cynthia* TO SOUND.

Age in Days.	Individuals Participating.			Number of Trials.			Per Cent. of Responses.		
	Males.	Females.	Total.	Males.	Females.	Total.	Males.	Females.	Total.
0–1	45	51	96	645	400	1,045	34	58	43
1–2	26	19	45	290	160	450	49	68	57
2–3	12	18	30	160	365	525	38	73	53
3–4	19	19	38	145	105	250	32	58	42
4–5	6	12	18	45	70	115	32	64	48
5–6	1	6	7	5	30	35	100	83	85
6–7	1	1	2	5	5	10	0	100	50
7–8	2	4	6	10	20	30	0	50	34
9–10	0	2	2	0	10	10	0	50	50

TABLE X.

EFFECT OF TEMPERATURE ON THE RESPONSES OF *Callosamia promethea* TO SOUND.

Temperature in F. Degrees.	Individuals Participating.			Number of Trials.			Per Cent. of Responses.		
	Males.	Females.	Total.	Males.	Females.	Total.	Males.	Females.	Total.
50–59	1	0	1	5	0	5	100		100
60–69	7	3	10	50	20	70	70	75	71
70–79	10	13	23	125	125	250	72	80	76
80–89	16	18	34	135	250	385	56	76	69
90–99	10	18	28	70	150	220	71	87	82
100–109	0	8	8	0	40	40		63	63

TABLE XI.

EFFECT OF MATING ON THE RESPONSES OF *Callosamia promethea* TO SOUND.

	Number of Individuals.	Number of Trials.	Per Cent. of Responses.
Males:			
Unmated.....	19	375	63
Mated.....	3	55	82
Total.....	21	430	67
Females:			
Unmated.....	15	515	80
Mated.....	3	62	80
Total.....	18	575	80

A careful perusal of the tables I–XII. shows that *S. cecropia*, *P. cynthia* and *C. promethea*, respond to a long range of sound waves. Since precautions were taken to prevent vibrations reaching them through any medium other than air, it seems

TABLE XII.

EFFECT OF AGE ON THE RESPONSES OF *Callosamia promethea* TO SOUND.

Age in Days.	Individuals Participating.			Number of Trials.			Per Cent. of Responses		
	Males.	Females.	Total	Males.	Females.	Total.	Males.	Females.	Total.
0–1	17	13	30	155	105	260	74	76	75
1–0	14	14	28	125	135	260	68	89	79
2–3	11	13	24	60	125	185	50	92	78
3–4	7	10	17	35	75	110	30	75	58
4–5	2	8	10	10	105	115	100	57	61
5–6	1	6	7	5	45	50	0	56	50
6–7	0	1	1	0	5	5		100	100
7–8	0	1	1	0	5	5		100	100

reasonable to conclude that they hear. How about *Telea polyphemus?* Of the seventy-eight individuals whose behavior is recorded in Table II. only three made any responses whatever. Of these three, two gave over ninety per cent. of responses and the other less than thirty. Shall we conclude that *Telea polyphemus* is deaf and that these few responses were due to some factor overlooked by the investigator; or, shall we consider the responses made by all of these moths as expressions of emotion, and attribute the non-responsiveness of *polyphemus* to a sluggish temperament?

To one who has worked much with *Telea polyphemus*, this last suggestion is fascinating; for this moth is exceptionally unresponsive to all ordinary stimuli. The opposite sex is about the only thing that arouses much activity. There is another possibility. *Telea polyphemus* is not a very conspicuous object; indeed, in certain situations, it might be considered protectively colored. It may be that correlated with this inconspicuous coloration is an instinct to remain rigidly immobile in the presence of all ordinary stimuli. To test the matter the following experiments were conducted.

A freshly emerged *Telea polyphemus*, the wings of which had become thoroughly dry, was tested with an organ pipe set to produce 256 vibrations per second. As was to be expected, there was no visible response. The organ pipe was then sounded five times in rapid succession. Immediately thereafter, the insect was roughly handled for a few minutes. It was tossed

about, gently squeezed and thrown upon its back. This was repeated over and over again, sometimes in one order and sometimes in another. After the moth had quieted down, the pipe was sounded five times in rapid succession. Each time the pipe was sounded, the moth waved its wings vigorously. At intervals of two hours, this experiment was repeated from early morning until dark. Invariably the moth responded in the same manner. On the following day the experiment was continued with the same moth. The result was always the same.

About a week later, similar experiments were conducted with two other specimens of the same moth. These, like the one used above, were females. With two exceptions, the results were identical. The exceptions were as follows: (1) one of the moths instead of moving its wings vigorously moved them slowly; the other two moths moved their wings so vigorously that they were lifted off of the support; in this case the body remained on the support, although the wings moved each time the whistle blew; (2) on two occasions a moth that had been experimented upon several times, instead of waiting for the five tones that were produced after the handling, waved its wings vigorously to each of the five preliminary notes. Evidently *Telea polyphemus* can hear. These experiments induced in those moths a state of nervous excitability which caused them to respond to the sounds produced.

Conclusions.

1. It seems certain that all four of the species of giant silkworm moths investigated can hear. Three of the species respond readily to a large range of sounds. The third, *Telea polyphemus*, normally does not respond to sounds; unless remaining as immobile as possible be considered a response. By experimentally causing the moth to associate some disagreeable experience with certain sounds, it can be induced to respond to those sounds.

2. There is much evidence that the responses of moths to stimuli are expressions of emotion. The fact that an insect does not respond to a sound is no sign that it does not hear it. The response depends upon whether or no the sound has a life significance.